WOODS HOLE OCEANOGRAPHIC INSTITUTION

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Status of World Gravity Studies Conducted by Woods Hole Oceanographic Institution and Present Problems in Global Gravity Measurements

by

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PREFACE

This report is supplemental to Woods Hole Oceanographic Institution Technical Report Reference No. 52-99 "World Wide Gravity Measurements conducted during the period June 1949 - January 1952" dated July, 1952 and Technical Report Reference No. 53-36 "A Study of Methods for Measuring Large Changes in Gravity on an Inter-Continental Basis", dated August, 1953. These reports represent work done under Contract N6onr-27704 (NR-081-091) with the Office of Naval Research, U. S. Navy and Contract AF19(122)-234 with the Cambridge Research Center of the U. S. Air Force respectively.

The purpose of this report is to give the status of the development of the world network of gravity bases established by this Institution and to point out those problems which must be solved on an international level of agreement before a homogeneous world-wide network of gravity bases can be achieved incorporating the work of all investigators.

INTRODUCTION

The development of high range gravimeters having a range of 2000 mgals. or more during the past decade has made it feasible to undertake gravity studies on a world-wide basis that 10 years ago would have been regarded as impractical. In particular, the advent of the Worden temperature compensated gravimeter has resulted in more international gravity measurements being made during the past 5 years than previously had ever been made. The Woods Hole Oceanographic Institution alone in its gravity program has established during the past 5 years more than 2000 gravity bases in 78 countries embracing most of the earth that is politically accessible. Other organizations such as L'Office de la Recherche Scientifique Outre Mer have carried out similar extensive gravimetric studies covering large portions of the earth, and in addition the number of submarine gravity stations has been more than doubled during the same period principally through the work of the Lamont Geological Observatory of Columbia University. Not counting pendulum equipment, there are now about 50 high range gravimeters suitable for inter-continental measurements distributed throughout the world and most of these are being rather extensively used.

This marked activity in the making of gravity measurements is directly related to (a) the development of suitable portable gravity instruments that have both high range and precision which can be read rapidly; and (b) a fuller realization of the application of gravity studies to the solution of fundamental problems in geodesy and geophysics. To successfully utilize the large mass of gravity data that is now being accumulated, it is necessary that the observations be referred to the same datum and that they conform to a fixed standard of accuracy both as regards individual station values and over-all value referred to absolute gravity.

The recognition of these requirements is not new, and the international adoption of the Potsdam absolute gravity base datum with each nation tying its national gravity base to Potsdam by relative gravity measurements with pendulums has been an attempt to satisfy the first of these requirements. The uncertainties in pendulum measurements however leaves much to be desired as regards their use for gravity standards as is evidenced by the 27 mgal. spread in the pendulum determined values for the Indian national gravity base at Dehra Dun. Although the use of gravimeters has reduced the probable error in such a series of repeat observations to less than $\pm$ 3 mgals. in even rather crude work, and less than $\pm$ 1 mgal. when more care is taken in making the measurements, the over-all accuracy on an absolute gravity basis may still be in considerable error. Whether the error is 1 mgal. or 30 mgals. will depend upon the basis of calibrating the individual gravimeter used.

One objective of this report is to discuss the latter source of error since it is already obvious that at the junction points of various gravimeter surveys made by different groups with different instruments the values are differing by too large an amount for certain studies. The causes of these differences therefore need to be examined and a solution determined on an international basis as soon as possible before any larger mass of gravity data accumulates.

STATUS OF WORLD GRAVITY MEASUREMENTS AT W.H.O.I.

World Network of Gravity Bases

Since the inception of the gravity program at the Woods Hole Oceanographic Institution in 1948 by the writer, most of the politically accessible countries of the world have been linked together in a common gravity network on the same datum. This datum is the Potsdam absolute gravity value for the U. S. Coast & Geodetic Survey national gravity base in the Department of Commerce Building in Washington, D. C., as adjusted by the writer (See reference 1). The adjustment was made on the basis of comparative gravimeter measurements to give the best fit to the national gravity base values on the Potsdam system in England, Denmark, France, Sweden, Holland, Finland, and Canada. This adjusted datum for the Commerce Building gravity base in Washington is 980.119 c.g.s. and is 1 mgal. higher than the value used by the U. S. Coast & Geodetic Survey. On this datum though the absolute gravity base of Heyl and Cook in the National Bureau of Standards in Washington has the same Potsdam value as that used by the U. S. Coast & Geodetic Survey due to a chance error of 1 mgal. in the earlier pendulum work which had tied both these bases directly to Potsdam.

The basis of calibration used in establishing the constants of the gravimeter used in the world network was a series of check observations against the Cambridge University (England) pendulums. These pendulums were used as a standard because of the small deviation (± 1 mgal.) of individual observations about the mean difference line over changes of gravity of 1000 mgals. or more and because of the general consistency of results in different parts of the world, particularly Australia and the British Isles. As will be shown in the following section there is now however some question about the absolute gravity values determined in high and low latitudes with the gravimeters using this calibration because of incomplete compensation for the effects of the earth's magnetic field on the Cambridge pendulums. The probable departures however are not regarded as

greater than 2 to 3 mgals. for every 1000 mgals. change in gravity north and south of Washington.

Other than the above uncertainty in absolute gravity values the results appear to be fairly reliable. For example, repeat observations on both the global encircling loop and numerous ties between North America and Europe show that individual gravity determinations were made with an average accuracy better than $\pm$ 0.5 mgal.

The development of the global gravity network to date under this program is shown in Figure 1, and the location of the principal gravity bases established on each continent are shown in Figure 2 through Figure 7. Additional work is planned in southern Europe, Africa, and the Arctic region and also in the Antarctic if the opportunity presents itself.

Regional Reconnaissance Surveys in the United States

In addition to the world-wide gravity studies the Woods Hole Oceanographic Institution is participating in the development of a reconnaissance network of gravity stations that is being established over the United States. This is a continuation of that started by the writer under the auspices of the Special Committee for the Geological and Geophysical Study of the Continents in 1939 and is supported in part by the Geological Society of America and the Air Force Cambridge Research Center.

Since regional surveys are now also being made by the U.S. Coast & Geodetic Survey as well as various university groups and a considerable amount of gravity material is being released by various oil companies, the present field program has been one of filling in gaps, furnishing control for adjusting oil company surveys to an absolute gravity datum, and developing the networks in areas not being investigated by other groups. This year the work is confined to the northwest states and particularly the area in and west of the Rocky Mountains. Here observations are being made at about 15 km. intervals along all of the principal highways. After another year's work a preliminary gravity reconnaissance of the country will be essentially completed.

Program of Gravity Reductions

As part of the present program, anomaly reductions are being made not only of the gravity observations now being taken

but also of other gravity data as that of oil companies. Considerable work however is attached to the use of much of the oil company data because of uncertainties in calibration of the instruments used and the use of other than a standard reference datum. In general it has proved necessary to adjust the observed gravity values to either an existing control network as the gravity bases of the U. S. Coast & Geodetic Survey or to a series of bases established especially for the purpose. These outside data are being secured through the Special Committee for the Geological and Geophysical Study of the Continents of the American Geophysical Union which for a number of years has been serving as a national coordinating agency on geophysical studies in the United States.

Tables of Principal Gravity Facts covering both Free Air and Simple Bouguer gravity anomalies are being prepared for all regional and world-wide observations taken to date, and will be published as a Woods Hole Oceanographic Institution Technical Report.

In addition to the above, gravity anomaly maps are also being drafted where there are sufficient data to permit contouring on a regional scale. Figure 8, a Bouguer isoanomaly map of the state of South Carolina, is an example of the type of map that it is felt can be prepared from existing reconnaissance data. Similar Free Air anomaly maps are not contemplated by this Institution since the U. S. Coast & Geodetic Survey has been preparing such maps.

In general, the program at the Woods Hole Oceanographic Institution has been one supplementing that of the U. S. Coast & Geodetic Survey and duplication has been avoided except in the case of special studies where it is to everyone's advantage to have duplicate studies.

PRESENT PROBLEMS IN GLOBAL GRAVITY MEASUREMENTS

General Statement

Although there are many problems involved in any program of field measurements that will affect the accuracy of the results obtained, it is not the purpose here to catalogue or discuss all those that are generally recognized in gravity measurements and which for the most part are handled in an adequate manner. The only problems that will be discussed are those that are not being handled adequately, or are r t being handled in a sufficiently uniform manner to permit results of a certain level of accuracy to be obtained.

Need for an International Gravity Standard

The adoption of an international gravity standard suitable for the calibration of gravity measuring instruments is at present the primary difficulty associated with making long distance gravity measurements involving changes of 1000 mgals. or more. At the moment there is no standard of calibration. The assumption that invariable pendulum measurements are adequate standards for calibration purposes is now definitely known to be in error. Comparisons made last year by this Institution of gravity values taken at the same sites using the Cambridge University magnetically compensated invar pendulums, the U. S. Coast & Geodetic Survey uncompensated invar pendulums, and the Gulf minimum length nonmagnetic quartz pendulums showed systematic differences in the observed value of gravity that amounted to as much as 6 mgals. for a change of 1000 mgals. This deviation was systematic and related to change ~~in latitude~~. Accumulatively between the Equator and the Poles the difference in gravity interval measured with the Gulf pendulums and those of the U. S. Coast & Geodetic Survey would have amounted to more than 30 mgals. The Cambridge University pendulums gave results intermediate between those obtained with ~~the Gulf~~ and U. S. Coast & Geodetic Survey pendulums. That is, they differed systematically from the Gulf pendulums by 2 mgals. for 1000 mgals. change and from the Coast & Geodetic Survey pendulums by 4 mgals. for 1000 mgals. change. These results are shown graphically in Figure 9 in which comparative results as obtained with the pendulums are plotted against those obtained with a gravimeter calibrated using the Cambridge pendulums as a standard. That the observed deviations are primarily related to the effect of changes in the earth's magnetic field on the period of the various pendulums involved is pretty well substantiated. The gravimeter comparisons for example carried out in Australia, the British Isles, and South Africa against the Cambridge pendulums when magnetically compensated using a Mu metal liner in the pendulum case and the comparisons made in North America when the Mu metal liner was removed and a Helmholtz coil substituted for stabilizing the vertical component of the earth's magnetic field showed a change of 1 mgal. for 1000 mgals. change in gravity. Through the use of a Helmholtz coil the U. S. Coast & Geodetic Survey also report that they are now getting results similar to those obtained with the Cambridge pendulums

This change in magnetic compensation, while obviously giving an improvement in results, however, apparently is not sufficient if the results obtained with the Gulf nonmagnetic quarts pendulums are correct. There still remains a discrepancy of 2 mgals. for 1000 mgals. change in gravity with latitude that is not accounted for. Whether this discrepancy is due to the emf induced by the swinging invar pendulums cutting the field of the horizontal component of the earth's magnetic field which

has not been stabilized, or a change in magnetic moment of the pendulums induced in travel, or a combination of these factors, or some other factor as yet undefined that might be affecting either the invar or quartz pendulums, cannot be said. For the purposes of this discussion this uncertainty is immaterial. The crucial point is that there is no set of pendulums that is generally accepted as giving a true measure of the change in gravity at the present time with an accuracy of greater than 10 mgals. between the Equator and the Poles, or that will suffice for the calibration of a geodetic type gravimeter to better than 2 parts in 1000.

Although it may be felt that the Gulf quartz pendulums are giving a better over-all measure of gravity than the invar equipment, this cannot be demonstrated since there is no absolute standard for comparison having the required accuracy. All that can be done is to point out that quartz is both highly stable and nonmagnetic; that the pendulums are minimum pendulums and thus the effect of knife edge wear is not as critical as with the invariable pendulums; that two pendulums are swung simultaneously 180° out of phase so as to effectively eliminate sway of supports; that the case is not opened at any time during a survey and thus there is no chance for dirt entering or changes in moisture content; that the air is desiccated and that pressure and density as well as temperature are maintained constant inside the case throughout a survey; that isochronism is essentially perfect; that time is determined with a crystal chronometer and rated against radio time signals; that there is no observed dependence in results on any factor likely to systematically influence the period of the pendulums such as building of electrostatic charges on the pendulums with time due to insufficient radioactive ionization of the residual atmosphere in the case; and that there is no known factor associated with latitude likely to influence the period of these pendulums because of the desirable physical properties of quartz.

Since the Gulf quartz pendulums have never been previously used for other than local surveys in oil exploration, where they gave results good to 0.2 mgal., these large observed systematic differences from invar pendulum results have not been previously reported. The discrepancies between older bronze pendulum measurements and those made with invar pendulums had always been attributed to imperfectly determined temperature coefficients for the bronze pendulums. In part at least it is now obvious the trouble lay with the invar pendulums.

Since the point has been raised that the present results obtained with the Gulf quartz pendulums were perhaps abnormal or peculiar to the set of pendulums used, and since there was a tare affecting some of the results the writer obtained the loan this year of two other sets of Gulf quartz pendulums from

the Gulf Research & Development Co. These are now being run over the same course as before between Fairbanks, Alaska, and Mexico City. Both sets of pendulums are being swung at each observation site so that there will be two independent sets of measurements over the entire range. It is also planned to fly the equipment south from Mexico City as far as Quito, Ecuador, making additional measurements en route in Guatemala, Nicaragua, Panama, and Colombia. The over-all range in gravity that will be covered by the measurements will be about 4,900 mgals. The number of observation sites will be approximately 40 in number. Since the Cambridge University pendulums are being swung by the Dominion Observatory of Canada over the Mexico City-Fairbanks, Alaska, portion of this line covering approximately 4,200 mgals., direct comparisons will be available between these two types of pendulums over a sufficient range in gravity to permit a thorough study of the differences obtained. A program is then planned to determine the causes of the differences in results obtained. Until this is done it does not appear desirable to undertake any world-wide adjustment of gravity values. Presumably these special comparative studies will be completed before the meetings of the International Association of Geodesy and Geophysics in Rome in 1954 and action can be taken at that time towards adopting an international gravity standard Even if such a standard is later proved to be in error, the adoption of an interim standard would have the immediate advantage of providing a mechanism for getting all measurements of gravity on a common basis.

Method of Geodetic Gravimeter Calibration

Just as there is no standard for comparison for gravity measurements there is no standard method for calibrating gravimeters. Most observers apparently are using the calibration furnished by the manufacturer or are calibrating their gravimeters by making multiple ties over relatively small intervals of gravity as determined by pendulum observations. No manufacturer as far as the writer is aware is now claiming a calibration better than 1 part in 2000; i.e., 1 mgal. accuracy for 2000 mgals. change. Furthermore this calibration applies only to that part of the instrument's range that can be readily checked. Tests of various makes of gravimeters by the writer have shown that the calibration constant for one portion of the scale may be quite different from that for another portion. The only positive solution appears to be to have a calibration range extending over a sufficiently large change in gravity to permit a calibration by direct comparison with standard values of gravity. It was with this objective that the original series of pendulum measurements with the Gulf quartz pendulums was planned in 1949 between Mexico City and Fairbanks, Alaska.

With the extension of this line of measurements to Quito, Ecuador, and the resolution of the present differences between pendulums it is believed a standardization range will be available for calibration purposes which can be occupied in its entirety in 16 days with a gravimeter using regular scheduled air transport. By starting in the middle, closures could be obtained on all observation points with a maximum of no more than 8 days closure time on the starting point. This is possible since all of the pendulum bases have been set at airports or tied to them directly by gravimeter measurements. As all airplane stops are for ten minutes or more there is ample time for a gravimeter observation to be made at each stopping point and travel can thus be continued on the same plane. A sample itinerary covering the entire route between Ecuador and Alaska, including travel from Washington using existing air transportation facilities is given in Table I.

As indicated in the itinerary given in Table I, 16 days would be required starting from Washington to make a round trip over this line of pendulum measurements. A change in gravity of 4,900 mgals. would be covered with observations at 32 control points and reoccupations for closure could be obtained at 22 of these. The inclusion of an additional two days would permit reoccupations of 30 of the bases. Of the closures obtained, approximately half of that observed could be accounted for by direct observations on drift during overnight stops, and it is not probable that an uncertainty of as much as 0.5 mgal. would be found in the final gravity values. If the pendulum values were accurate to 1 mgal. on an absolute basis a calibration good to approximately 1 part in 10,000 would be had and at the same time the degree of linearity of the gravimeter would be determined over its entire range. The desirability of having such a standardization range therefore cannot be overemphasized. Even if no agreement can be reached concerning the absolute gravity accuracy of the pendulum values on the Alaska-Ecuador line of measurements, this series of gravity bases will still probably constitute the most reliable gravity standard yet established for calibrating high range gravimeters.

A word in closing this section might be in order concerning the accuracy of the tilt table calibrations furnished with the Worden geodetic gravimeters since so many of these instruments are now in use throughout the world. Through the cooperation of the Houston Technical Laboratory tilt table calibrations were made by Mr. William Black of this Institution and the University of Wisconsin on two Worden instruments at Madison, Wisconsin (g = 980.3684) and at Fairbanks, Alaska (g = 982.2514). and the results compared with those obtained in Houston (g = 979.2956). The instruments were found to have a markedly different calibration at each of these three places and none agreed

TABLE I

Flying time itinerary over gravity calibration range between Alaska and Ecuador G signifies Gulf quartz pendulum base. C signifies base occupied with Cambridge University pendulums. U signifies base occupied with U. S. Coast & Geodetic Survey pendulums.

	1st day via Capitol A. L.	
GCU	Washington, D. C.	lv 0840
G	Chicago, Ill.	1156
	Chicago via N.W.A.L.	lv 1430
GCU	Madison, Wis.	1525
	Minneapolis, Minn.	1659
	2nd day via Western A.L.	
	Minneapolis, Minn.	lv 1000
GCU	Huron, S. D.	1210
G	Cheyenne, Wyo.	1634
GU	Denver, Colo.	1718
	3rd day via Western A.L.	
	Denver, Colo.	lv 0700
G	Cheyenne, Wyo.	0748
G	Casper, Wyo.	0848
G	Sheridan, Wyo.	0957
G	Billings, Mont.	1046
G	Lewiston, Mont.	1147
G	Great Falls, Mont.	1232
	Great Falls, Mont.	lv 1315
G	Cutbank, Mont.	1354
GC	Lethbridge, Alb. Can.	1436
	Lethbridge via Can. Pac. A.L.	lv 2000
GC	Edmonton, Alb., Can.	2145
	4th day via Can. Pac. A.L.	
	Edmonton, Alb., Can.	lv 1120
GC	Grand Prairie, Alb.	1300
GC	Ft. St. John, B. C.	1410
	Ft. St. John, B. C.	lv 1525
GC	Ft. Nelson, B. C.	1580
GC	Watson Lake, Yukon	1640
GC	Whitehorse, Yukon	1825
	5th day via Pan. Am. A.L.	
	Whitehorse, Yukon	lv 1645
GCU	Fairbanks, Alaska	1830
	6th day in Fairbanks, Alaska	
	7th day via Pan Am. A.L.	
	Fairbanks, Alaska	lv 0800
GC	Whitehorse, Yukon	1215
	8th day via Can. Pac. A.L.	
	Whitehorse, Yukon	lv 0800
GC	Watson Lake, Yukon	0930
GC	Ft. Nelson, B. C.	1210
GC	Ft. St. John, B. C.	1435
	Ft. St. John, B. C.	lv 1510
GC	Grand Prairie, Alb.	1605
GC	Edmonton, Alb.	1750

TABLE I (Cont'd.)

	9th day via Western A.L.		
	Edmonton, Alb.	lv	0833
GC	Lethbridge, Alb.		1018
G	Cutbank, Mont.		1100
G	Great Falls, Mont.		1200
G	Lewiston, Mont.		1300
G	Billings, Mont.		1410
G	Casper, Wyo.		1547
GU	Denver, Colo.		1725
	10th day via Braniff A.L.		
GU	Denver, Colo.	lv	0700
G	Colorado Springs		0730
G	Amarillo, Texas		1020
	Amarillo, Texas	lv	1100
G	Dallas, Texas		1340
	Dallas, Texas	lv	1425
GCU	Houston, Texas		1535
GCU	Houston via E.A.L.	lv	1752
G	San Antonio, Texas		1922
	San Antonio via Am. A.L.	lv	2000
GC	Monterrey		2120
GC	Mexico City		2340
	11th day via Pan. Am. A.L.		
	Mexico City	lv	0800
G	Guatemala City		1113
G	Managua, Nicaragua		1506
G	Tocumen, Panama		1919
	12th day via Pan. Am. A.L.		
	Tocumen, Panama	lv	0715
G	Cali, Colombia		1030
G	Quito, Ecuador		1240
	13th day via Pan. Am. A.L.		
	Quito, Ecuador	lv	1150
G	Cali, Colombia		1400
	Tocumen, Panama		1700
	14th day via Pan. Am. A.L.		
	Tocumen, Panama	lv	0800
G	Managua, Nicaragua		1000
G	Guatemala City		1251
GC	Mexico City		1636
	Mexico City	lv	1700
GCU	Houston, Texas		2035
	15th day via Braniff A.L.		
	Houston, Texas	lv	0730
G	Dallas, Texas		0840
	Dallas, Texas	lv	0915
G	Denver, Colo.		1233
	Denver via United A.L.	lv	1500
G	Chicago, Ill.		2015
	Chicago, Ill.	lv	2350
GCU	Washington, D. C.		0320

with the calibration based on pendulum station reoccupations except the tilt table value at Houston which checked with the value based on the present Cambridge University pendulums as magnetically compensated with a single Helmholtz coil. Upon completion of the present summer's work, which will include a run with a gravimeter over the Alaska-Ecuador line of pendulum bases, it will be extremely interesting and significant to determine which, if any, of the various pendulum measurements confirm the nonlinearity with latitude indicated by the tilt table measurements.

Processing of Raw Gravity Data

In addition to the problem of calibration there is at present no uniformity in either the method of determining instrumental "drift" with gravimeters or the method used in applying closures incorporating both drift and "tares" (jumps) in readings introduced by sudden shocks or knocks. Some groups tend to follow the procedures adopted in geophysical prospecting and be as precise as is practical. That is, sufficient closures are taken to permit the short-term drift rate to be determined and with this procedure "tares" due to shock can be easily located and corrected. Other groups apparently are determining drift on the basis of the over-all closure for the period of an entire survey which may involve two or three months or more. This procedure assumes a uniform drift rate with no tares in the readings. While such a procedure simplifies computations and speeds up field progress it is not conducive to the best results.

In addition to the above some groups are handling tares in readings as lump sum corrections while others appear to be distributing such corrections throughout a whole network of stations. This latter procedure in the writer's opinion is to be condoned only as a last resort when the place of occurrence of a known tare cannot be adequately determined. Because of individual differences in drift rate and susceptibility to tares of different gravimeters as well as differences in accuracy required for different surveys, no set standard procedure can be established for carrying out the field work as regards determining closures or for adjusting the data for closures. However there should be a record submitted to a central agency indicating field procedure used, the characteristics of the instrument, and the method of closure adjustment employed so that the data can be evaluated on a relative basis with other data.

While on the subject of closures, a word should be said about the reliability of results obtained with instruments

having high drift rates (1 to 2 mgals. per day). The impression has been given at various times that results obtained with such instruments are not nearly as reliable as those obtained with instruments having a low drift rate or better yet no drift. The writer's experience in using various instruments having these characteristics is that just as reliable and sometimes even better results are obtained with those instruments having a marked drift rate. This anomalous condition results from the fact that an effort is made to obtain frequent closures with an instrument having a known high drift rate and as a consequence tares are detected and allocated as to place of occurrence which would not be so easily detected with a driftless meter with which only infrequent closures are taken.

Tares are also found in pendulum measurements as well as gravimeter measurements and the only safeguard against such effects is frequent closures. In the present line of pendulum stations between Alaska and Ecuador closures will be obtained at at least 8 sites. The entire line has already been double run and most of it triple run with gravimeters and therefore there will be no difficulty in determining the place at which a tare occurs or its magnitude. In this way a proper correction can be applied and none of the values will be biased as would be the case if final closure value representing perhaps the net effect of two or more tares, possibly not all of the same sign, was distributed over all the stations occupied.

CONCLUSION

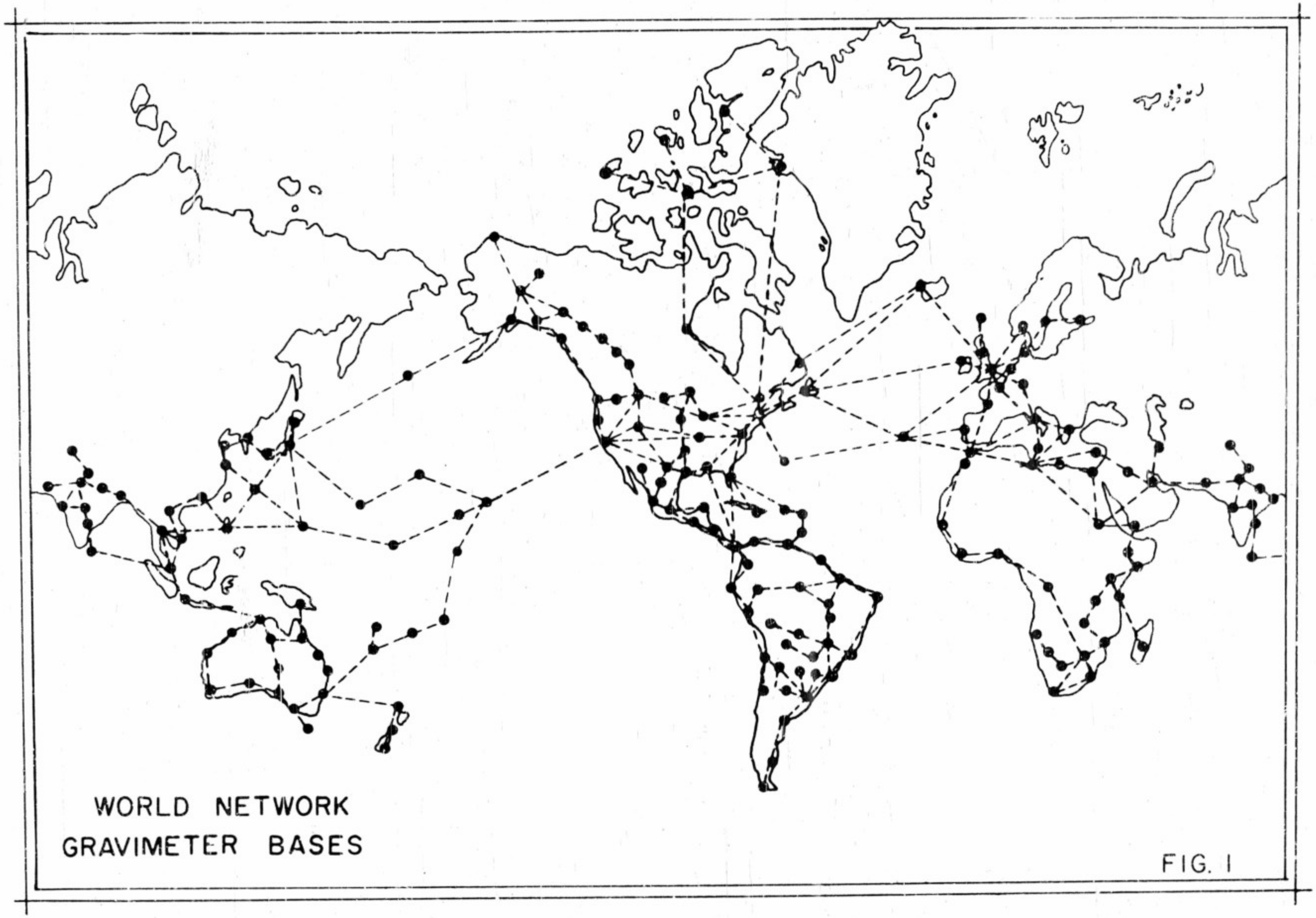
For the purposes of carrying out world-wide geodetic and geophysical studies incorporating all of the world's gravity data it is essential that these data be integrated and adjusted to a set standard having a given accuracy. It has been shown that present standards, namely, relative pendulum measurements, are not uniform and further may vary greatly. In addition present field and reduction procedures are so variable as to constitute contributing factors to some of the differences in results being obtained. The most important factor though, is the lack of an international gravity standard that can be used as a basis of gravity instrument calibration and intercomparison of all gravity measurements. Although enough interconnecting work has now been carried out to permit adjustment and integration of most of the world's gravity networks it is not possible to do so because there is no general agreement as to what the standard is to be.

The present comparative measurements being made cooperatively by the Woods Hole Oceanographic Institution using the

nonmagnetic Gulf quartz pendulums, the Dominion Observatory of Canada using the Cambridge University invar pendulums with magnetic compensation and the U. S. Coast & Geodetic Survey using their invar pendulums, it is believed will furnish the basis for arriving at a satisfactory gravity standard. Until these measurements and studies are completed, however, it does not appear wise to adopt a standard, or to attempt to adjust the various international gravity networks into an integrated whole.

REFERENCE

1. Woollard, G. P., "The Gravity Meter as a Geodetic Instrument". Geophysics, Vol. 15, No. 1, pp. 1-29. 1950.



WORLD NETWORK
GRAVIMETER BASES

FIG. I

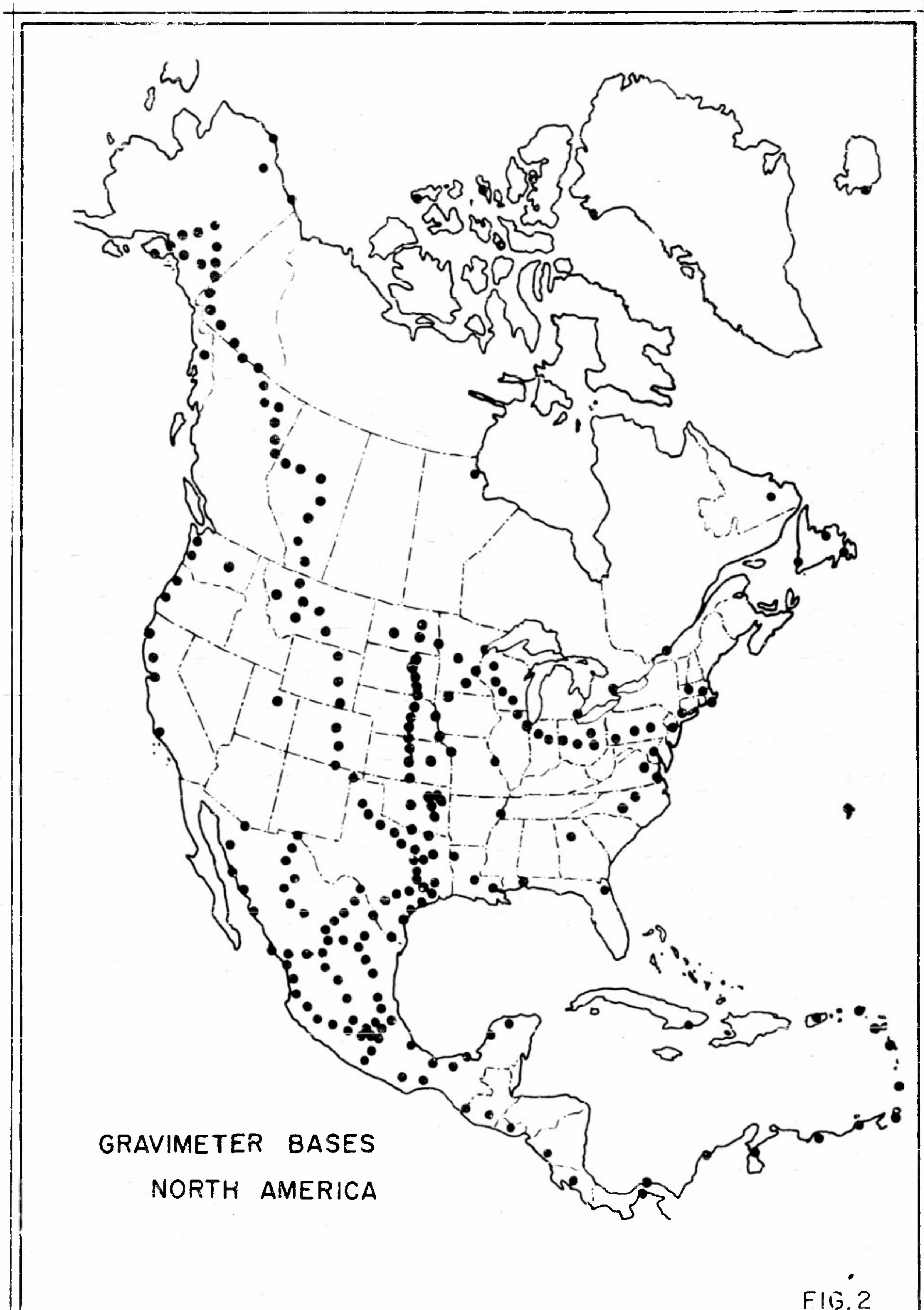
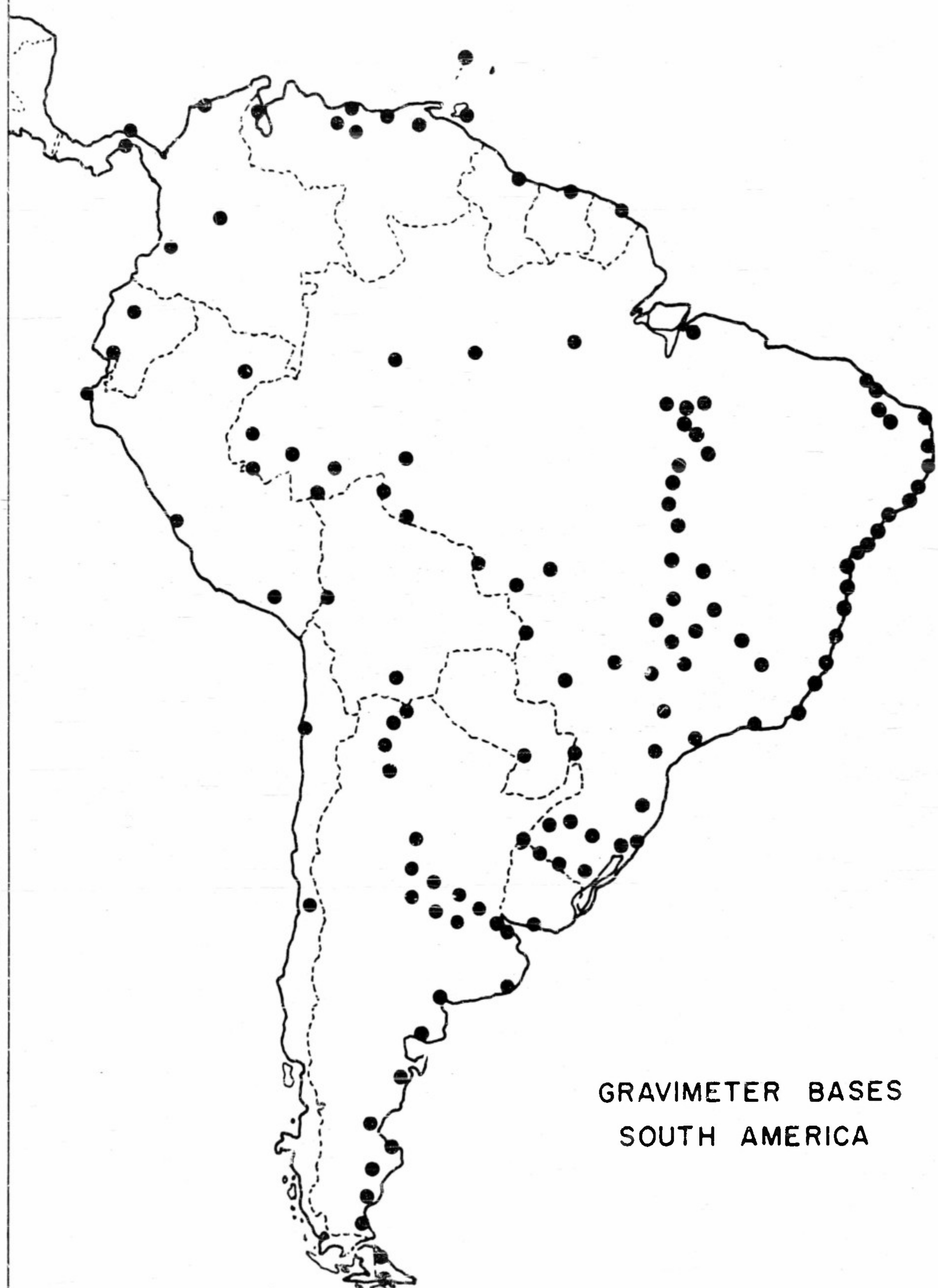


FIG. 2



GRAVIMETER BASES
SOUTH AMERICA

FIG. 3

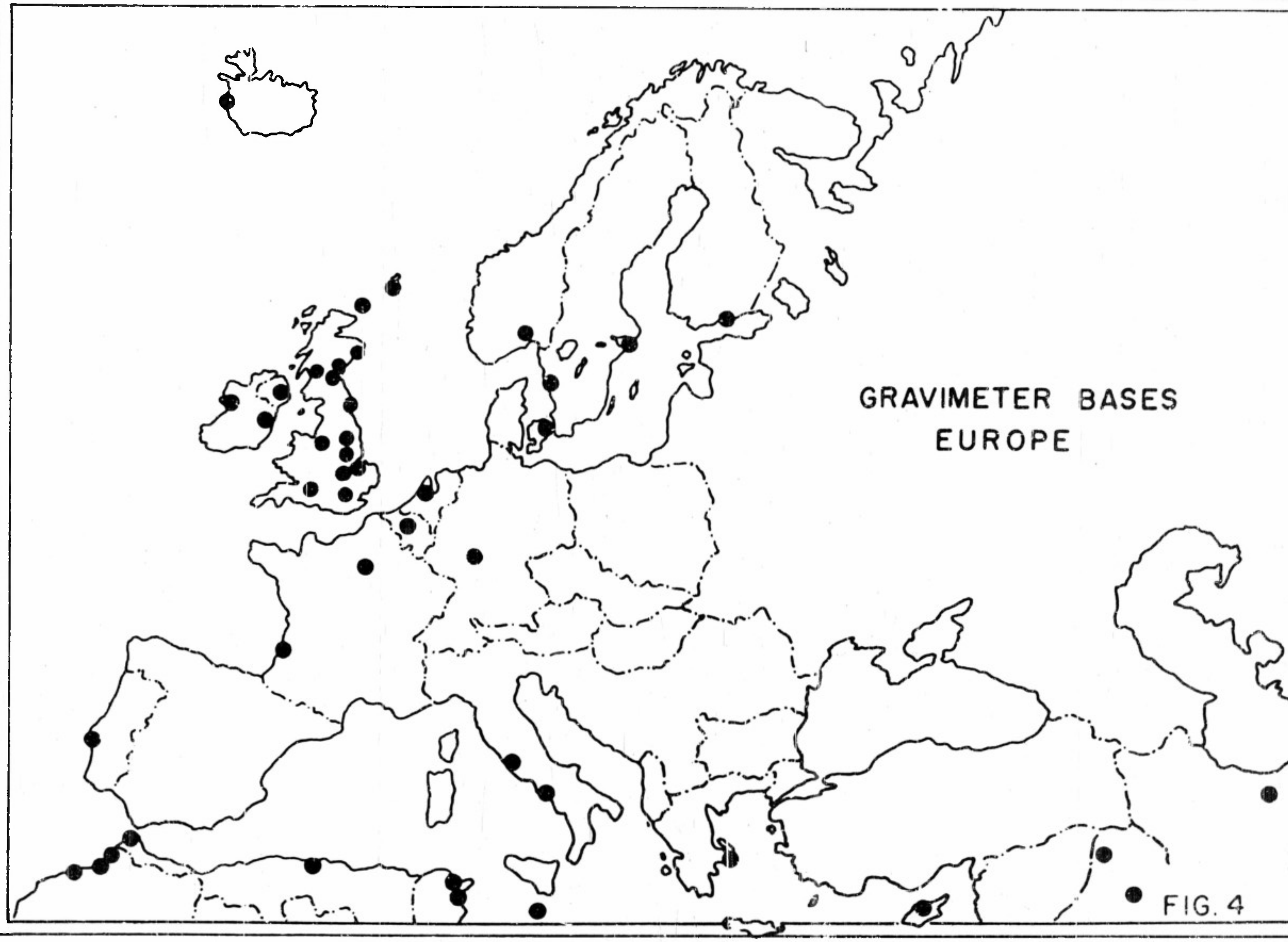


FIG. 4

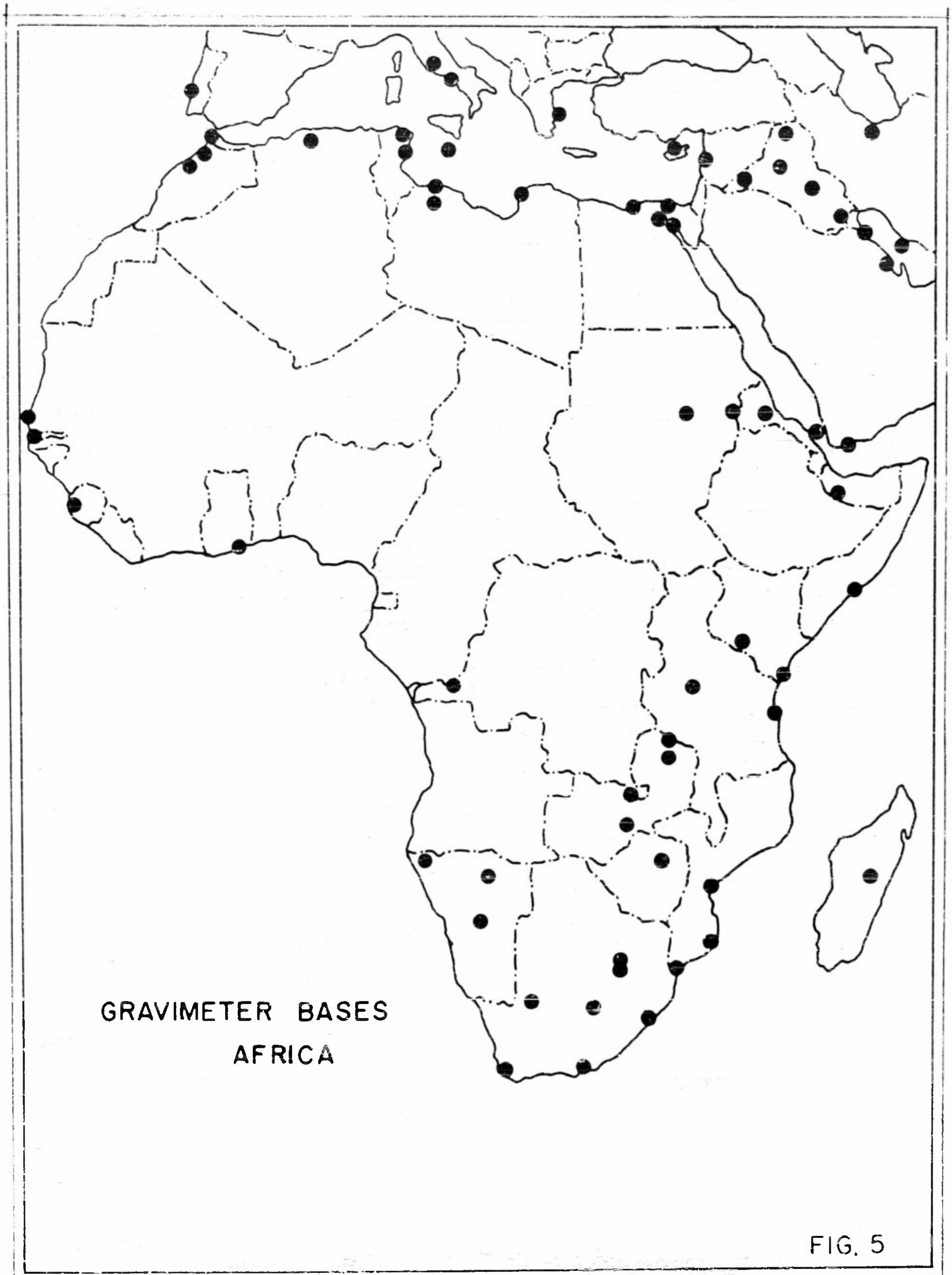


FIG. 5

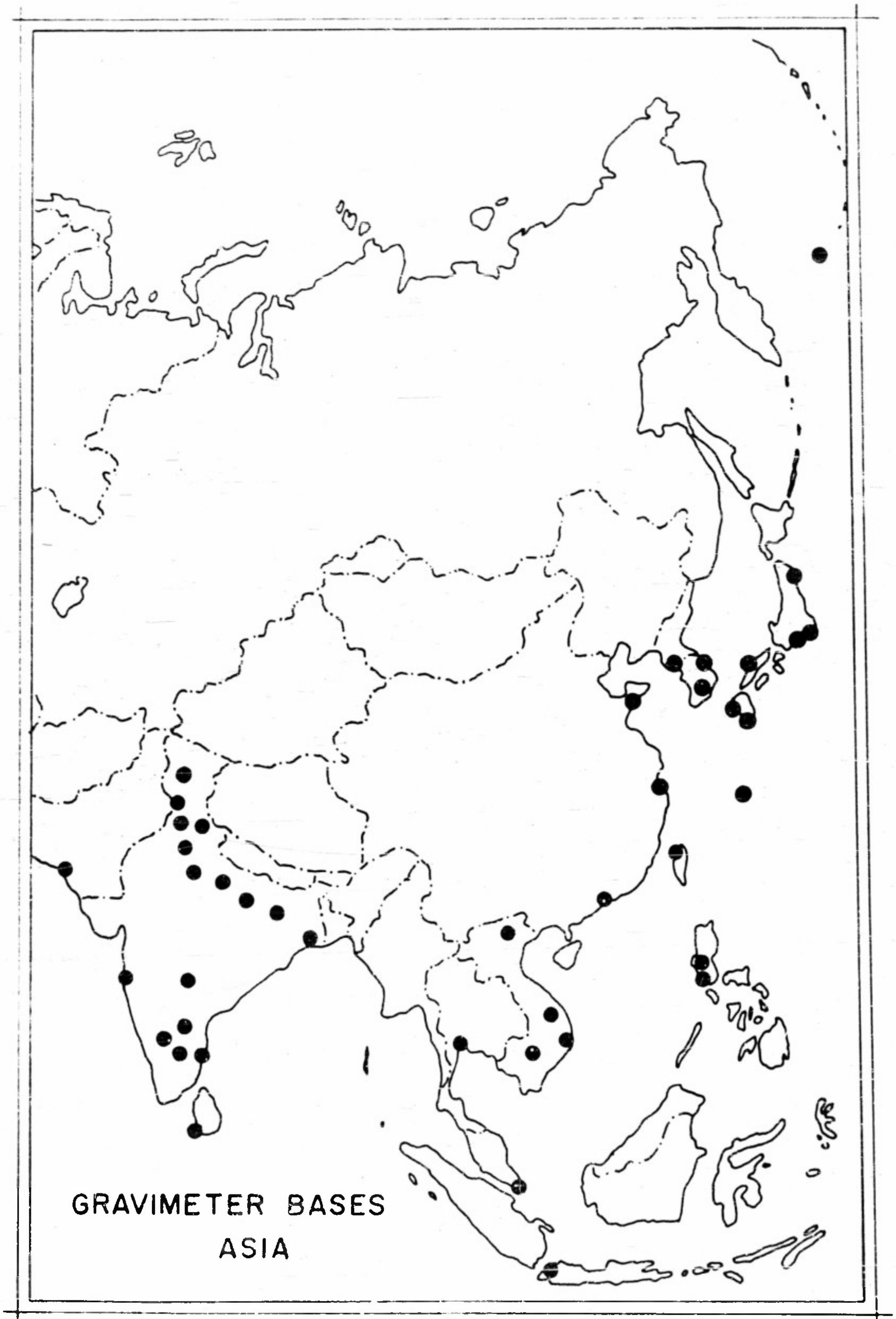


FIG. 6

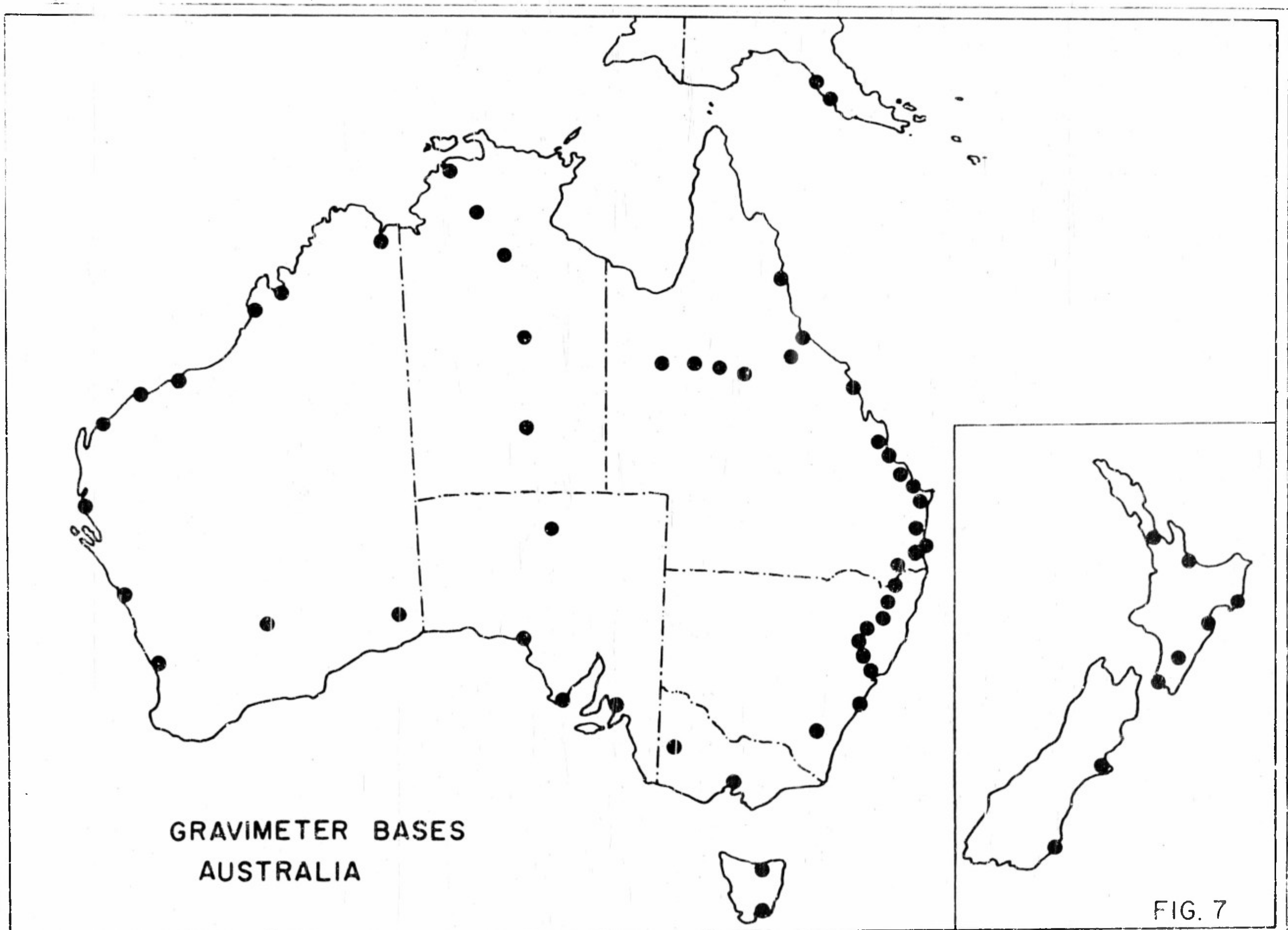
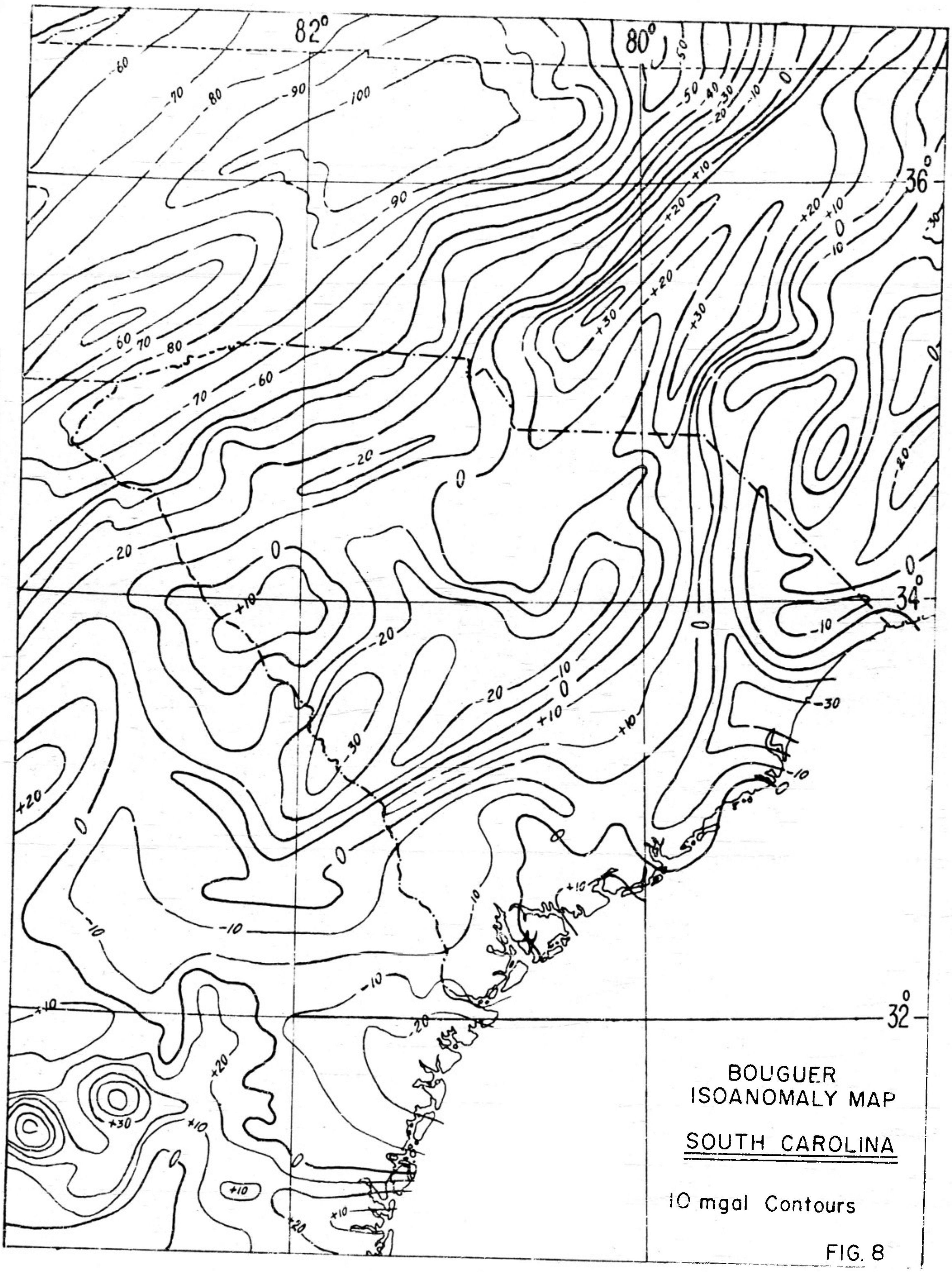


FIG. 7



BOUGUER
ISOANOMALY MAP

SOUTH CAROLINA

10 mgal Contours

FIG. 8

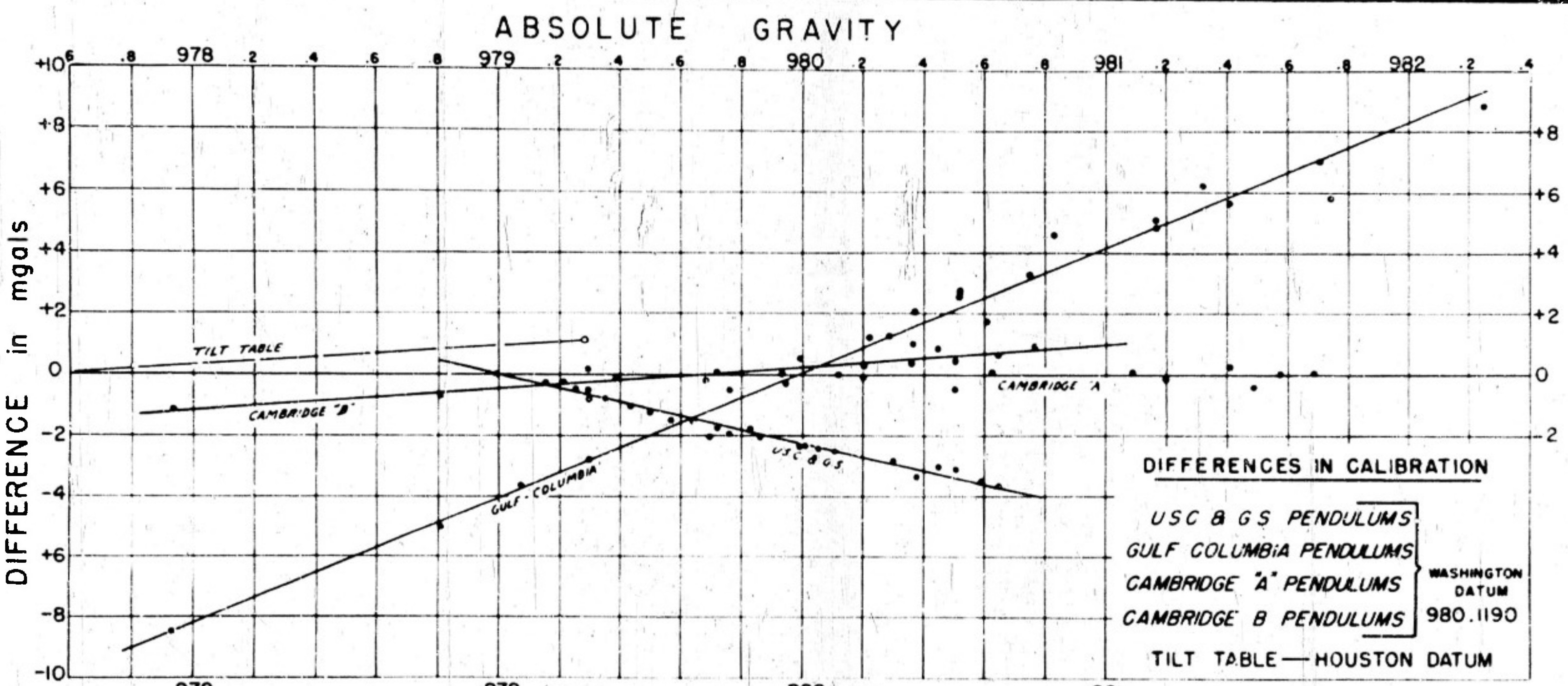

ABSOLUTE GRAVITY
DIFFERENCE in mgals
TILT TABLE
CAMBRIDGE "B"
CAMBRIDGE A
USC & GS
GULF - COLUMBIA
DIFFERENCES IN CALIBRATION
USC & GS PENDULUMS
GULF COLUMBIA PENDULUMS
CAMBRIDGE "A" PENDULUMS
CAMBRIDGE B PENDULUMS
WASHINGTON DATUM
980.1190
TILT TABLE — HOUSTON DATUM

FIG. 9

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